## 10.0.  Forward Projection Approach-Application and Description

An initial base case forward projection model was developed and refined.  Surveys, stock-recruitment, and hydroacoustic information were all given equal weighting (1) in the final model.

### 10.1.  Growth

Growth was modeled using a time-series of mean weight at age data from thecommercial landings during 1967-2000.  These were used to estimate von Bertalanffy parameters (Schnute form for KLAMZ (FPA) model, see appendix 1) for the 1968-2000 year classes, beginning at age 1 (which is one year before recruitment at age 2 in the model).  A von Bertalanffy curve was fit to the data for each cohort assuming a common value of K for all cohorts and cohort specific W-infinity and t-zero values.  Problems were encountered with negative predicted weights at age 1 for some cohorts so the series average was substituted for the predicted values at age one in all years (e.g. 0.015 g was used as the predicted value for weight at age one for all cohorts).  Values of j were calculated as:

$$j = {wt(1)}\Big/{wt(2)}$$

The j values were then calculated and used with von-Bertalanffy parameters in the model to estimate annual growth changes (see appendix 1 for details).

### 10.2.  Maturity

Maturity was assumed to be 0.0 at age 2 and 1.0 at age 3 and older (see below).

## 10.3.  Maturity Data From Acoustics Studies

Herring maturity stages were recorded during biological sampling of herring during the 1999-2002 hydroacoustics cruises.  Age 2 herring were all immature and age 3 + fish were mature.  The overall maturity status of herring was different in each of the survey years.  In all years, most of the fish observed were in a developing stage, but the relative proportions were different in each year (Figure 10.1).  In 1999 about 20% of the mature fish were ripe, with smaller proportions in subsequent surveys (Figure 10.1).

In 1999, about 20% of the fish were ripe in the first Georges Bank survey and about 30% in the last survey (Figure 10.2).  No spent or resting herring were observed in 1999.  In 2000, a few ripe fish were sampled during the first survey and about 7-8% were spent thereafter (Figure 10.3).  In 2001, 2-3% of the herring were spent or resting during the first survey, and between 14-22% were spent and 4-5% were resting on the subsequent surveys (Figure 10.4).  In 2002, only one survey was completed, 14% of the herring were spent and 16% were resting (Figure 10.5).

The large proportion of spent and resting fish encountered during 2002 suggests that a large proportion of the spawning fish were not encountered by the survey.  This is the likely reason why the survey biomass estimate in 2002 is so low compared to previous surveys.  Biomass in 2002 was expected to increase due to growth of several large year classes (1994, 1998) in the spawning stock.

## 10.4.  Natural Mortality

Natural mortality (M) was assumed equal to 0.2 as in previous assessments (NEFSC 1998).  The forward projection analysis allows for the estimation of annual changes in M by modeling deviations from a mean value (see Appendix 1), but this feature was not used in the current assessment.

## 10.5. Recruitment

Recruitment was modeled with a Beverton-Holt stock-recruitment relationship with alpha and beta parameters estimated internally by the model (see Appendix 1 for details). A Ricker modeling formulation was tried, but was less satisfactory than the Beverton-Holt model.

## 10.6. Variability in recruitment

Annual variability in recruitment for herring in the model was measured by log scale recruitment residuals:

$$r_t = \ln[Exp(R_t)] - \ln(R_t)$$

where $Exp(R_t)$ is the expected value of recruitment based on a recruitment model (see Recruitment Models in Appendix 1). The variance of log scale recruitment residuals $(\sigma_r^2)$ is important because it is used to compute the log likelihood of recruitment estimates and to estimate model parameters (Appendix 1). This variance was estimated, rather than specifying it as a fixed and predetermined quantity as in NEFSC (2001).

Estimation of $\sigma_r^2$ in the model used prior information about ten North Atlantic herring stocks from the Stock Recruitment Database.[1] All North Atlantic herring stocks with at least 15 spawner-recruit observations were used (Table 10.1). The Gulf of Maine and Georges Bank herring stocks were not used as prior information although variances were calculated for comparison.

To estimate variances, nonparametric stock-recruit models (which were smooth loess regression lines) were fit to spawning biomass and log transformed recruitment data for each stock. Most data sets showed evidence of a spawner-recruit relationship but the shape of the relationship varied from stock to stock (Figure 10.6) as:

$$\sigma_r^2 = \sum_{j=1}^{N} r_j^2 \bigg/ (N - d_f)$$

for each stock. The distribution of residual variances for the 10 herring stocks was skewed to the right but log transformed variances were approximately normal (Figure 10.7) with

---

[1] Stock-recruitment database maintained by R. Myers at Dalhousie University; see www.mscs.dal.ca/~myers/welcome.html.

mean= -0.707, median= -0.818 and variance= 1.02. The median was used as the measure of central tendency instead of the mean because the median of ten observations is more robust. Thus, the log likelihood of the prior estimates (or log prior probability) given the model's estimate of $\sigma_r^2$ was computed:

$$L = 0.5 \frac{\left[\ln\left(\sigma_r^2\right) - (-0.818)\right]^2}{1.02}$$

## 10.7. Surplus Production

Surplus production for the herring complex was estimated using a Fox (1975) stock production model. Parameters were estimated internally and $\lambda$ was set at 0.0001. A Schaefer (1954) model was also estimated by fitting a quadratic equation to the calculated surplus production after the model converged as:

$$Y = \alpha B - \beta B^2$$

where Y is the yield and B is the biomass.

## 10.8. Landings

A time-series of total landings for the Gulf of Maine-Georges Bank region during 1959-2002 were used in the model (Table 10.2). These data were obtained from NMFS, Maine DMR, DFO Canada, and ICNAF and NAFO sources. The total was composed of landings from the US fishery in the Gulf of Maine and on Georges Bank, Canadian landings on Georges Bank and in the New Brunswick weir fishery, and reported landings from foreign nations during 1961-1978.

## 10.9. Research Surveys

A total of eleven research survey time-series were used to tune the model. Atlantic herring catch/tow indices (age 2 and age 3+) from MNFS winter (1992-2002), spring (1968-2002) and autumn (1963-2002) groundfish surveys were used (Table 10.3). Survey number per tow indices were converted to weight per tow indices by applying US fishery weight at age data

Atlantic herring catch per tow indices from Canadian groundfish surveys during 1986-2002 were also used for tuning.  The same procedure applied to the US surveys was used for converting number/tow indices to weight/tow indices (Table 10.3).

Larval herring survey indices from both USA and Canada were used as tuning indices of spawning biomass.  The US survey series covered 1971-1994 and the Canadian survey 1987-1995 (Table 10.4).

Biomass estimates from US hydroacoustic surveys during 1999-2002 were also used to model trend.  These data represent the overall biomass encountered in each acoustic survey of herring (Table 10.4).  The estimates for 1999-2001 represent a weighted average of the three acoustic surveys conducted in each of those years. In 2002, only one herring acoustic survey was conducted.

## 10.10.  Survey Covariates

The NMFS autumn time-series, 1963-2002 has been an erratic measure of herring abundance and biomass since its start in 1963.  Few herring were captured during the early part of the series 1963-1974, in spite of herring being abundant during much of this time period.  Herring catches during the middle part of the series were low, but so was abundance.  Herring were seemingly much more available during the mid 1980s and 1990s, and autumn survey catches were relatively high.  Because of the inconsistencies in this survey, several hypotheses were examined that might explain the apparent changes in catchability in the autumn time-series.   Impacts of temperature on the catchability of herring were hypothesized, so temperature data were obtained for the Gulf of Maine and Georges Bank during both the spring and autumn.  These data consisted of average surface and bottom temperatures and temperature anomalies for both seasons.  The GOM series was analyzed since all the spawning components utilize this area: both the surface and bottom temperatures were used with one number expressing both values.  By differencing the autumn surface and bottom series from the GOM, an increasing trend was detected (Figure 10.8).  However, if this trend were real it should have also been present in the temperature anomalies for the region, but this was not the case (Figure 10.9).

It was noted that the timing of the autumn survey might have changed during 1963-2002.  The mean and median Julian date for the autumn survey in each year were obtained and plotted

(Figure 10.10). A distinct declining trend in survey timing is evident since the early 1960s (Figure 10.10). The fall survey residuals were also negatively correlated to fall survey timing (Figure 10.11).

A temperature effect was selected to represent any of several processes that might influence the aerial and depth distribution of herring, ultimately affecting catchability. As such an effect could profoundly influence survey catches of herring, a variable was added to the total likelihood representing this effect on q via:

$$I = qB \text{ and } I = q'B$$

where

$$q = q'e^{\alpha T}$$

where T is the standardized temperature anomaly ((surface-bottom)-mean of the surface-bottom)) and $\alpha$ is the estimated parameter for the autumn survey during 1963-2002. The spring surface-bottom gradient was also calculated and unlike the autumn, exhibited no trend (Figure 10.12). As the spring survey showed no trend in timing (Figure 10.13), and spring survey residuals were not related to spring timing, no attempt was made to correct for timing changes of the spring.

It was hypothesized that the use of polyvalent doors beginning in 1985 may have affected the catch of herring in the NMFS spring and autumn surveys. Although the coefficient for weight per tow for herring was not significant at the p=.203 level from the door conversion experiments that were conducted, these experiments were not designed to estimate the effects of the door change on herring. So, an indicator variable approach for introducing the door change effect variable to the likelihood function as:

$$q' = qe^{\delta D}$$

where $\delta$ is the estimated parameter and D is 1 during 1985-2002 and 0 for all other years in the spring and autumn surveys. If both survey covariates are used in the model they would be estimated as:

$$q = qe^{\alpha T + \delta D}$$

In initial model fits, adding a covariate for doors improved the fit of the spring surveys for both age 2 (Figure 10.14b vs. Figure 10.14c) and age 3+. For age 2 the addition of a dummy covariate for doors was significant in a simple t-test (t=7.17), but the covariate for spring age 3+ was not significant.

Adding a door covariate also improved the residual pattern for the autumn survey age 2 and 3+ indices in the NMFS aautumn survey (Figure 10.15).

Adding a temperature covariate for survey timing also produced better fits and lower residuals for both autumn age 2 and age 3 indices (Figure 10.15E).

The combination of door and temperature covariates greatly improved the residual patterns for the autumn survey (Figure 10.15F). Simple t-tests for age 2 were significant for doors (t=9.43) and age 3+ for doors and temperature(t=2.70, 3.62).

## 10.11.  Acoustic Results Used to Scale Biomass

Biomass estimates from 1999-2002 acoustic surveys were available for scaling the forward projection modeling results.  To develop an appropriate ratio for the proportion of Georges Bank fish to the overall complex total, information from the US acoustic surveys, previous assessments, and acoustic surveys conducted by ME DMR-GOM Aquarium was used.

1. Georges Bank biomass estimate from acoustic surveys 2001      1.82 million mt
    Gulf of Maine biomass estimate NEFSC (1998)                  0.40 million mt
        1.82/2.22=0.82

2. Georges Bank biomass estimate from acoustic surveys 2001      1.82 million mt
    Gulf of Maine biomass estimate from acoustic surveys 2001     0.32 million mt
        1.82/2.14=0.85

3. Gulf of Maine acoustic surveys from commercial vessels revealed an order of magnitude difference in average biomass between the Gulf of Maine and Georges Bank during 1999 and 2000 (Figure 10.16)
        1999      30/300 = 10%
        2000       30/330 = 9%        ~ 90%  Georges Bank

Based on these resultsa Q ratio of 0.85 was selected as the proportion of Georges Bank fish (age 2+) represented in the US acoustic surveys.  A prior distribution with mean $\tau$ and CV= $\varphi$ (see Appendix 1 for details) was used as:

$$NLL = [\frac{\ln(Q) - \tau}{\varphi}]^2$$

where tau was determined to be ln(0.85) and phi is the log scale sd=0.597 (CV=0.429). Q represents the proportion of the Georges Bank component in the coastal herring complex, determined from several independent sources.

## 10.12. Survey Diagnostics and Residuals

Plots of survey residuals for the eleven time-series used to tune the model were used as diagnostic measures of goodness of fit (Figures 10.16-10.19). The US spring age 2 and age 3+ seem to fit well with few residual patterns or clumping (Figure 10.17). The US winter survey age 2 does not fit particularly well, and the age 3+-winter survey residual fit is only somewhat better; however, both series are relatively short (Figure 10.17). The US fall age 2 survey residuals fit fairly well as do the US fall age 3+ residuals (Figure 10.17). The hydroacoustic survey series is very short (1999-2002) and the diagnostic plots show a large contrast between the 2001 and 2002 data (Figure 10.18). The US larval survey performs fairly well, but has a string of positive residuals at the end of the series (Figure 10.18). The Canadian larval survey also performs well, but has a large residual in 1991 (Figure 10.18). The Canadian age 2 spring survey does not fit well, exhibiting several large residuals and some clumping of residuals (Figure 10.19). The Canadian age 3+ residuals fits well, showing an even distribution and only a small amount of clumping (Figure 10.19).

## 10.13. Sensitivity Analyses

### *Likelihood Profiles*

A likelihood profile analysis was completed for Q values ranging between 0.1-1.7. The best fit occurred when Q=1.3 for non-surveys and Q=0.5 for the survey components of the likelihood (Table 10.5). The lowest likelihood component values for the surveys occur at both ends of the spectrum. The low component likelihood value for the spring age 3+ and the Canadian larval survey occur at Q values of 1.1 or greater (Table 10.5). The lowest values for the rest of the surveys occur at Q values of 0.5 or less (Table 10.5).

Table 10.1.  Variance, number of observations, and degrees of freedom from spawner recruit models for various North Atlantic stocks of herring.

| Stock | Variance $(\sigma_r^2)$ | N | Residual Degrees of Freedom ($d_f$) |
|---|---|---|---|
| Used in analysis | | | |
| Downs Stock | 0.57 | 65 | 62.0 |
| Gulf of Finland | 0.45 | 18 | 14.6 |
| ICES VIa(north) | 0.32 | 18 | 14.0 |
| ICES Via(south) and VIIb,c | 0.27 | 19 | 15.1 |
| Iceland (spring spawners) | 1.77 | 23 | 20.0 |
| Iceland (summer spawners) | 0.40 | 49 | 45.0 |
| NAFO 4-5[1] | 0.43 | 22 | 18.3 |
| North Sea | 0.47 | 41 | 37.5 |
| Northern Irish Sea | 0.08 | 18 | 14.4 |
| Norway (spring spawners) | 3.36 | 44 | 40.4 |
| *Not used in analysis:* | | | |
| Georges Bank | 2.35 | 30 | 26.8 |
| Gulf of Maine | 0.62 | 46 | 43.1 |
| summary_recr_var_1.xls | | | |

1 Includes Gulf of Maine and Georges Bank components.

Table 10.2.  Landings (2+, 000s mt) of Atlantic herring from the Gulf of Maine-
Georges Bank complex during 1959-2002.

| | |
|---|---|
| 1959 | 94.001 |
| 1960 | 93.955 |
| 1961 | 100.556 |
| 1962 | 242.150 |
| 1963 | 194.344 |
| 1964 | 187.445 |
| 1965 | 109.844 |
| 1966 | 210.038 |
| 1967 | 285.245 |
| 1968 | 469.978 |
| 1969 | 392.655 |
| 1970 | 307.131 |
| 1971 | 330.520 |
| 1972 | 271.744 |
| 1973 | 258.551 |
| 1974 | 209.886 |
| 1975 | 216.957 |
| 1976 | 121.925 |
| 1977 | 67.080 |
| 1978 | 88.165 |
| 1979 | 104.178 |
| 1980 | 93.234 |
| 1981 | 84.097 |
| 1982 | 59.852 |
| 1983 | 35.627 |
| 1984 | 42.442 |
| 1985 | 55.155 |
| 1986 | 56.202 |
| 1987 | 66.846 |
| 1988 | 73.950 |
| 1989 | 97.059 |
| 1990 | 93.805 |
| 1991 | 79.943 |
| 1992 | 93.191 |
| 1993 | 88.667 |
| 1994 | 76.821 |
| 1995 | 102.253 |
| 1996 | 126.852 |
| 1997 | 119.553 |
| 1998 | 125.829 |
| 1999 | 124.101 |
| 2000 | 125.818 |
| 2001 | 133.165 |
| 2002 | 104.430 |

Table 10.3 Research survey catch per tow (kg) for age 2 and age 3+ for US winter, spring, and fall and Canadian spring during 1963-2002.

| Year | US Win 2 | US Win 3+ | US Sp 2 | US Sp 3+ | US Fall 2 | US Fall 3+ | Can 2 | Can 3+ |
|------|----------|-----------|---------|----------|-----------|------------|-------|--------|
| 1963 |          |           |         |          | 0.0007 | 0.6396 |        |         |
| 1964 |          |           |         |          | 0.0006 | 0.0865 |        |         |
| 1965 |          |           |         |          | 0.0000 | 0.3492 |        |         |
| 1966 |          |           |         |          | 0.0002 | 1.0030 |        |         |
| 1967 |          |           |         |          | 0.0017 | 0.3234 |        |         |
| 1968 |          |           | 0.0385 | 4.0238 | 0.0006 | 0.1304 |        |         |
| 1969 |          |           | 0.0046 | 2.8576 | 0.0009 | 0.0648 |        |         |
| 1970 |          |           | 0.2425 | 0.7814 | 0.0019 | 0.0583 |        |         |
| 1971 |          |           | 0.0098 | 0.3326 | 0.0007 | 0.3329 |        |         |
| 1972 |          |           | 0.0240 | 0.4417 | 0.0065 | 0.0734 |        |         |
| 1973 |          |           | 0.0036 | 1.4868 | 0.0000 | 0.0071 |        |         |
| 1974 |          |           | 0.0014 | 0.9982 | 0.0000 | 0.0179 |        |         |
| 1975 |          |           | 0.0019 | 0.2122 | 0.0004 | 0.0621 |        |         |
| 1976 |          |           | 0.0018 | 0.1968 | 0.0000 | 0.0229 |        |         |
| 1977 |          |           | 0.0025 | 0.1729 | 0.0003 | 0.0046 |        |         |
| 1978 |          |           | 0.0049 | 0.4572 | 0.0004 | 0.0940 |        |         |
| 1979 |          |           | 0.1450 | 0.6270 | 0.0004 | 0.0023 |        |         |
| 1980 |          |           | 0.0046 | 1.0499 | 0.0000 | 0.0006 |        |         |
| 1981 |          |           | 0.0009 | 0.5044 | 0.0000 | 0.0011 |        |         |
| 1982 |          |           | 0.0198 | 0.0425 | 0.0002 | 0.0198 |        |         |
| 1983 |          |           | 0.0084 | 0.0686 | 0.0020 | 0.0230 |        |         |
| 1984 |          |           | 0.0985 | 0.1550 | 0.0005 | 0.2244 |        |         |
| 1985 |          |           | 0.0957 | 0.3465 | 0.0017 | 0.3821 |        |         |
| 1986 |          |           | 0.8970 | 4.2002 | 0.0012 | 0.1428 | 0.0963 | 1.2768 |
| 1987 |          |           | 0.0572 | 0.8099 | 0.0890 | 0.9074 | 0.0355 | 0.0136 |
| 1988 |          |           | 0.1098 | 1.4101 | 0.0345 | 1.2456 | 0.0137 | 0.5563 |
| 1989 |          |           | 0.0763 | 1.1943 | 0.0643 | 1.8146 | 3.1252 | 0.4792 |
| 1990 |          |           | 0.1307 | 0.8733 | 0.1144 | 1.2696 | 1.5893 | 0.2202 |
| 1991 |          |           | 0.2428 | 2.2723 | 0.1432 | 1.9079 | 2.0854 | 8.1996 |
| 1992 | 0.3544 | 3.2568 | 0.5060 | 2.7256 | 0.1032 | 6.3418 | 0.4042 | 4.9939 |
| 1993 | 0.0140 | 6.5446 | 0.3186 | 7.6045 | 0.0156 | 2.3624 | 0.0193 | 30.0806 |
| 1994 | 0.0040 | 0.5886 | 0.2131 | 3.8900 | 0.0311 | 1.7832 | 0.0179 | 0.2981 |
| 1995 | 0.0041 | 2.6609 | 0.3396 | 2.9269 | 0.0327 | 9.7751 | 0.0975 | 4.8333 |
| 1996 | 4.0268 | 5.8776 | 2.2093 | 3.2156 | 0.5835 | 3.7706 | 1.7286 | 2.4164 |
| 1997 | 0.0810 | 8.6201 | 0.9788 | 4.7696 | 0.0839 | 4.3264 | 0.9881 | 31.0152 |
| 1998 | 0.0689 | 6.6631 | 0.1918 | 5.5111 | 0.0654 | 2.5404 | 0.0601 | 3.1638 |
| 1999 | 0.0130 | 7.6771 | 0.1271 | 10.7960 | 0.0120 | 1.6884 | 0.0322 | 41.2759 |
| 2000 | 2.9168 | 9.1597 | 0.9217 | 2.6557 | 0.0672 | 3.1045 | 28.4954 | 7.0423 |
| 2001 | 0.3642 | 8.7139 | 0.3058 | 3.7324 | 0.0184 | 3.7760 | 0.1243 | 47.8367 |
| 2002 | 0.4000 | 9.3000 | 0.0200 | 2.5000 | 0.1500 | 10.8981 | 0.0500 | 15.0000 |

Table 10.4.  Time series of survey catch for the US acoustic survey (000's t), the US larval survey (# larvae/10 m$^2$), and the Canadian larval survey (# larva/ m$^2$) during 1971-1995

| Year | US Acoustic | US Larval | Canadian Larval |
|------|-------------|-----------|-----------------|
| 1971 |  | 89.7 |  |
| 1972 |  | 81.4 |  |
| 1973 |  | 355.2 |  |
| 1974 |  | 304.5 |  |
| 1975 |  | 55.9 |  |
| 1976 |  | 2.2 |  |
| 1977 |  | 19.2 |  |
| 1978 |  | 2.4 |  |
| 1979 |  | 6.0 |  |
| 1980 |  | 1.9 |  |
| 1981 |  | 29.7 |  |
| 1982 |  | 18.2 |  |
| 1983 |  | 3.7 |  |
| 1984 |  | 2.3 |  |
| 1985 |  | 95.4 |  |
| 1986 |  | 60.4 |  |
| 1987 |  | 31.4 | 12.59 |
| 1988 |  | 184.9 | 6.05 |
| 1989 |  | 454.3 | 7.37 |
| 1990 |  | 394.1 | 10.21 |
| 1991 |  | 354.2 | 3.29 |
| 1992 |  | 577.1 | 12.17 |
| 1993 |  | 397.6 | 30.35 |
| 1994 |  | 610.0 | 52.26 |
| 1995 |  |  | 41.29 |
| 1996 |  |  |  |
| 1997 |  |  |  |
| 1998 |  |  |  |
| 1999 | 1193.0 |  |  |
| 2000 | 1427.0 |  |  |
| 2001 | 1819.0 |  |  |
| 2002 | 763.0 |  |  |

Table 10.5.  Likelihood profile analysis for base case forward projection model.  Profile runs were carried out by fixing the scaling parameter (*Q*) for the herring hydroacoustic survey to values between 0.5 and 1.7.  The basecase run had *Q*=0.91.  In rows with negative log likelihood values, the lowest value (indicating best fit) is shaded and in a bold-italic font.

| Profile results: | Profile run with Q=0.5 | Profile run with Q=0.6 | Profile run with Q=0.7 | Profile run with Q=0.8 | Basecase Q=0.91 | Profile run with Q=1.1 | Profile run with Q=1.3 | Profile run with Q=1.5 | Profile run with Q=1.7 |
|---|---|---|---|---|---|---|---|---|---|
| **Weighted likelihoods used by model** | | | | | | | | | |
| Non Survey | 7.80 | -12.73 | -13.71 | -14.24 | *-14.47* | -14.32 | -13.74 | -12.95 | -12.05 |
| Surveys | *399.49* | 413.20 | 413.26 | 413.35 | 413.44 | 413.62 | 413.80 | 413.98 | 414.15 |
| Total | 407.29 | 400.47 | 399.56 | 399.11 | *398.97* | 399.30 | 400.05 | 401.03 | 402.10 |
| **Unweighted likelihoods for profile analysis** | | | | | | | | | |
| Non Survey | 17.12 | -42.00 | -48.05 | -52.61 | -56.47 | -61.51 | *-63.06* | -61.64 | -59.00 |
| Surveys | *399.49* | 413.20 | 413.26 | 413.35 | 413.44 | 413.62 | 413.80 | 413.98 | 414.15 |
| Total | 416.61 | 371.20 | 365.21 | 360.74 | 356.97 | 352.11 | *350.74* | 352.33 | 355.16 |
| **Unweighted non survey likelihood components** | | | | | | | | | |
| PriorQ_Hydroacoustic_3+ | 0.59 | 0.21 | 0.04 | *0.00* | 0.06 | 0.35 | 0.77 | 1.26 | 1.79 |
| Recruitment Model | 7.60 | -15.39 | -16.76 | -17.65 | -18.18 | *-18.44* | -18.16 | -17.61 | -16.97 |
| Constrain_first_few_recruitments | -0.60 | -1.75 | -1.82 | -1.86 | -1.88 | *-1.89* | -1.88 | -1.85 | -1.82 |
| Fox_surplus_production | 9.48 | -25.49 | -30.01 | -33.65 | -37.05 | -42.11 | *-44.37* | -43.99 | -42.52 |
| Prior_Log_Rec_Residual_Var | *0.02* | 0.42 | 0.48 | 0.52 | 0.55 | 0.56 | 0.55 | 0.52 | 0.49 |
| Constrain_inital_IGR | 0.03 | *0.01* | *0.01* | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 |
| **Unweighted survey trend likelihood components** | | | | | | | | | |
| Trend_Spring_Age_2 | *57.75* | 63.29 | 63.70 | 64.01 | 64.28 | 64.66 | 64.94 | 65.16 | 65.33 |
| Trend_Spring_Age_3+ | 51.87 | 51.18 | 50.65 | 50.18 | 49.71 | 48.92 | 48.20 | 47.58 | *47.06* |
| Trend_Winter_Age_2 | *19.50* | 20.62 | 20.71 | 20.77 | 20.83 | 20.91 | 20.97 | 21.01 | 21.05 |
| Trend_Winter_Age_3+ | *8.06* | 8.19 | 8.28 | 8.36 | 8.43 | 8.55 | 8.65 | 8.74 | 8.82 |
| Trend_Fall_Age_2 | *71.72* | 76.26 | 76.34 | 76.37 | 76.38 | 76.37 | 76.37 | 76.37 | 76.40 |
| Trend_Fall_Age_3+ | *74.08* | 74.61 | 74.41 | 74.37 | 74.42 | 74.70 | 75.11 | 75.55 | 75.99 |
| Trend_Hydroacoustic_3+ | *15.28* | 16.04 | 16.02 | 15.98 | 15.94 | 15.83 | 15.70 | 15.54 | 15.36 |
| Trend_Larval_Herring_Index | *41.45* | 42.11 | 42.10 | 42.10 | 42.12 | 42.18 | 42.24 | 42.29 | 42.34 |
| Trend_Canadian_Larval_Survey | 6.05 | 6.08 | 6.08 | 6.07 | 6.06 | 6.04 | 6.02 | 6.00 | *5.98* |
| Trend_Canadian_Age_2 | *26.53* | 28.05 | 28.12 | 28.18 | 28.23 | 28.30 | 28.36 | 28.40 | 28.43 |
| Trend_Canadian_Age_3+ | 27.20 | *26.75* | 26.87 | 26.96 | 27.05 | 27.16 | 27.26 | 27.33 | 27.39 |
| | | | | | | | | | |
| **Recent average F (2000-2002)** | 0.04 | 0.05 | 0.05 | 0.06 | 0.07 | 0.08 | 0.10 | 0.11 | 0.13 |
| **Recent average B (2000-2002)** | 3,258 | 2,743 | 2,362 | 2,076 | 1,844 | 1,532 | 1,309 | 1,145 | 1,020 |
| **Log(recruitment variance)** | 0.53 | 0.17 | 0.16 | 0.16 | 0.15 | 0.15 | 0.15 | 0.16 | 0.16 |
| **Fox Production modeling (biomass * 0.001)** | | | | | | | | | |
| K_(carrying_capacity)= | 3.10 | 4.27 | 3.46 | 2.87 | 2.43 | 1.99 | 1.78 | 1.69 | 1.64 |
| Bmsy= | 1.14 | 1.57 | 1.28 | 1.06 | 0.90 | 0.73 | 0.66 | 0.62 | 0.60 |
| MSY= | 0.24 | 0.27 | 0.24 | 0.23 | 0.22 | 0.22 | 0.21 | 0.21 | 0.20 |
| Fmsy= | 0.21 | 0.17 | 0.19 | 0.22 | 0.25 | 0.30 | 0.33 | 0.34 | 0.34 |
| Recent_F/Fmsy= | 0.18 | 0.27 | 0.28 | 0.28 | 0.28 | 0.28 | 0.30 | 0.33 | 0.37 |
| Recent_B/Bmsy= | 2.86 | 1.75 | 1.85 | 1.97 | 2.06 | 2.09 | 1.99 | 1.84 | 1.69 |

**Maturity Stages 1999-2002**
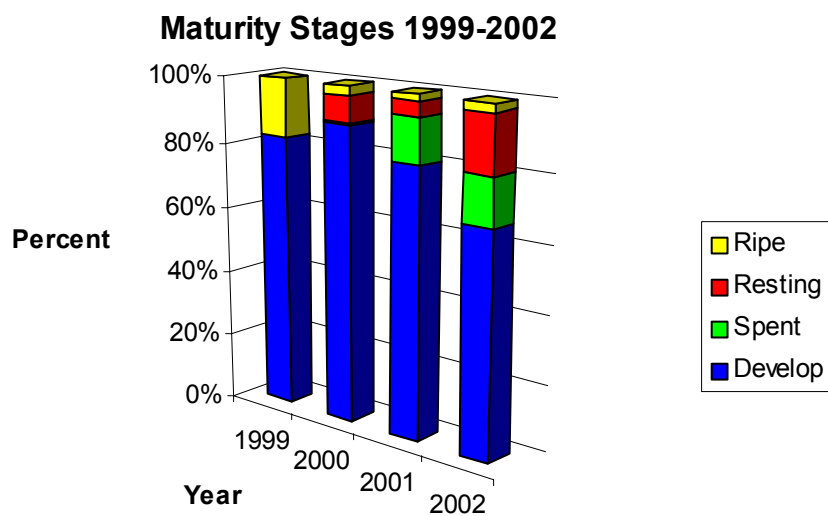
Figure 10.1. Overall proportion of mature herring at different maturity stages during acoustic survey cruises during 1999-2002
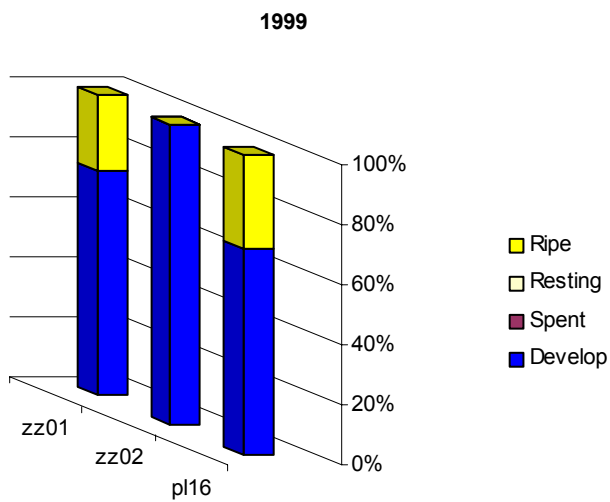
Figure 10.2. Maturity stages observed during consecutive herring acoustic surveys (starting with zz01) on Georges Bank during 1999.
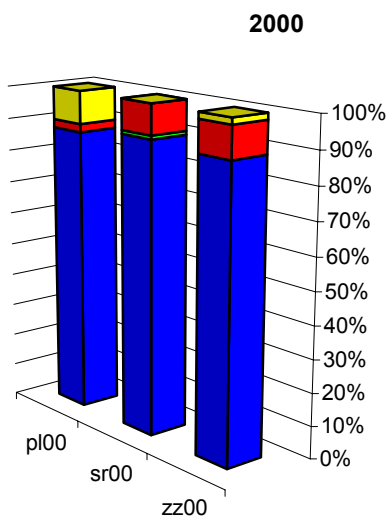


Figure 10.3. Maturity stages observed during consecutive herring acoustic surveys (starting with pl00) on Georges Bank during 2000
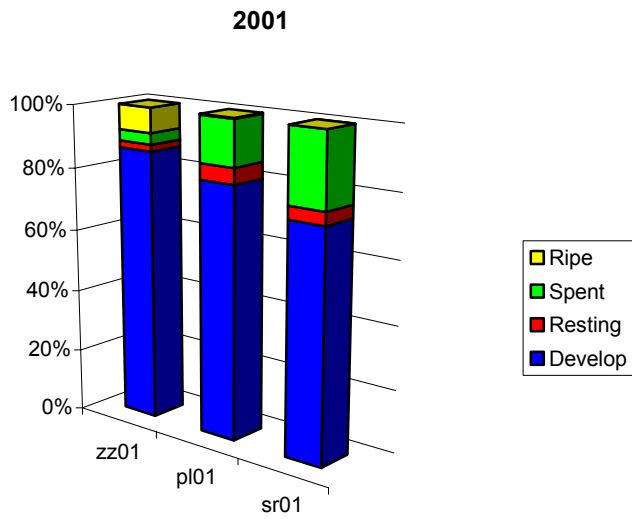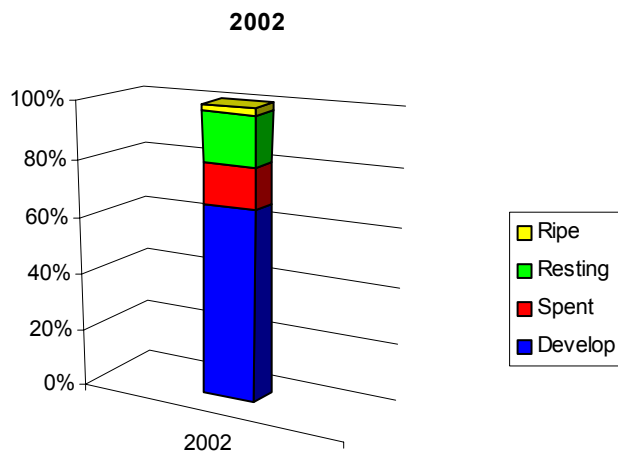
**2001**



Figure 10.4.  Maturity stages observed during consecutive herring acoustic surveys (starting with zz01) on Georges Bank during 2001

**2002**



Figure 10.5.  Maturity stages observed on a herring acoustic survey on Georges Bank during 2002.
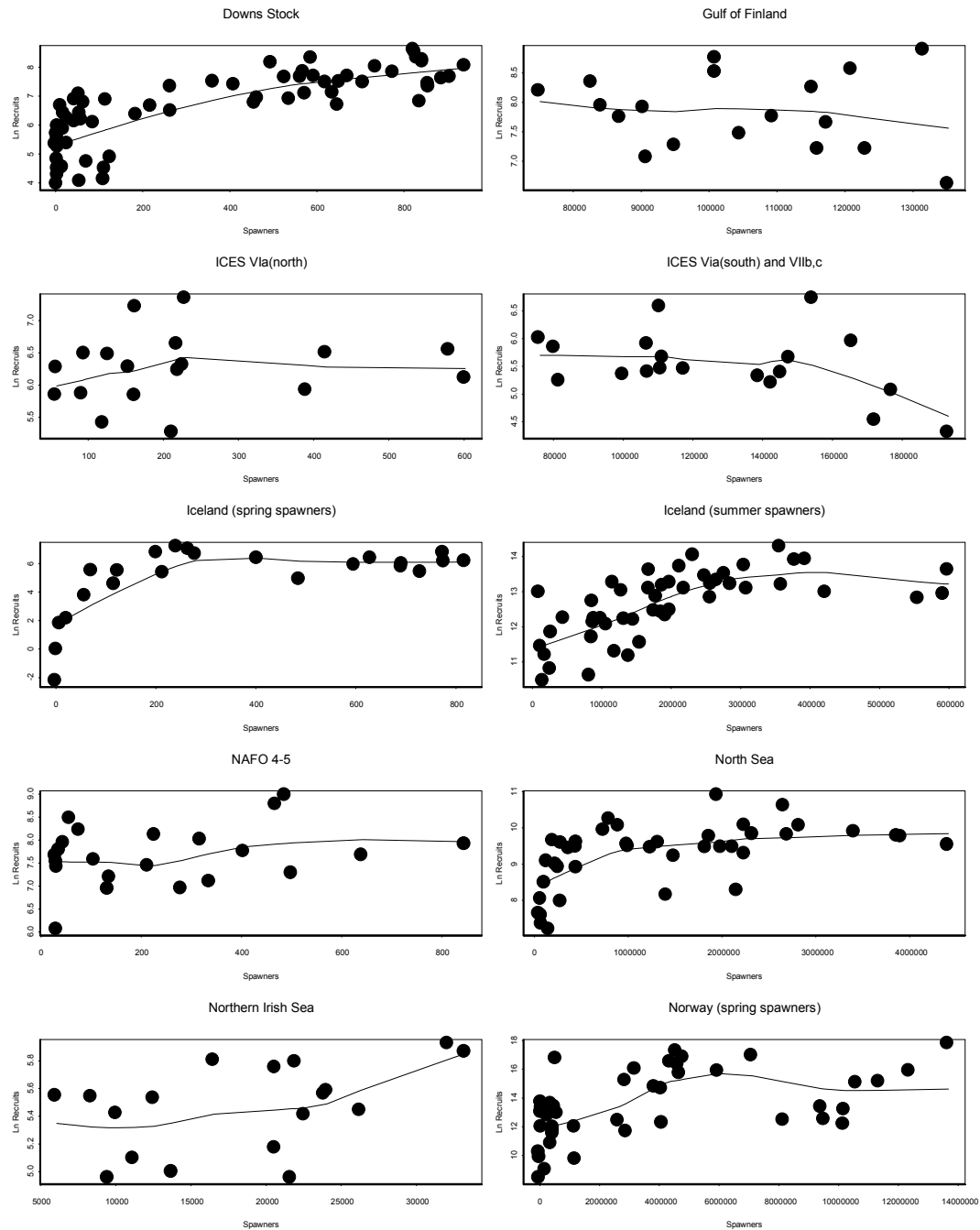
Figure 10.6. Log recruit numbers plotted against spawning biomass for ten North Atlantic Herring Stocks. Smooth lines are nonparametric stock-recruit models fit by loess regression.
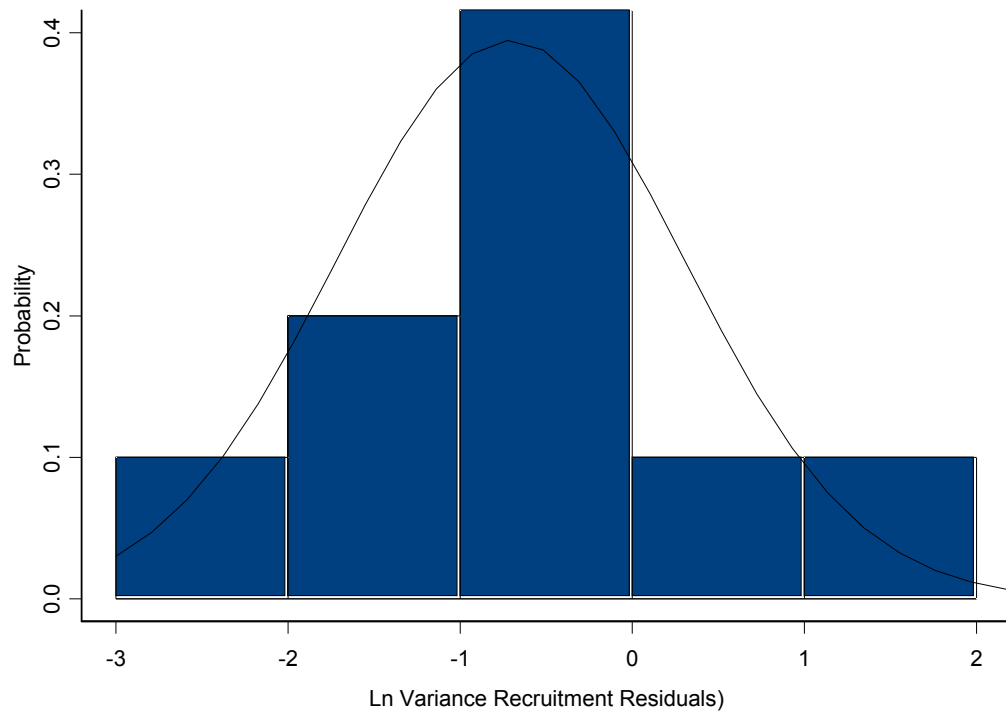
Figure 10.7. Distribution of variance estimates for log recruitment residuals from nonparametric stock recruit models for ten North Atlantic herring stocks.

**GOM Autumn Surface Bottom Gradient**

$$y = 0.0492x - 94.319$$
$$R^2 = 0.2683$$
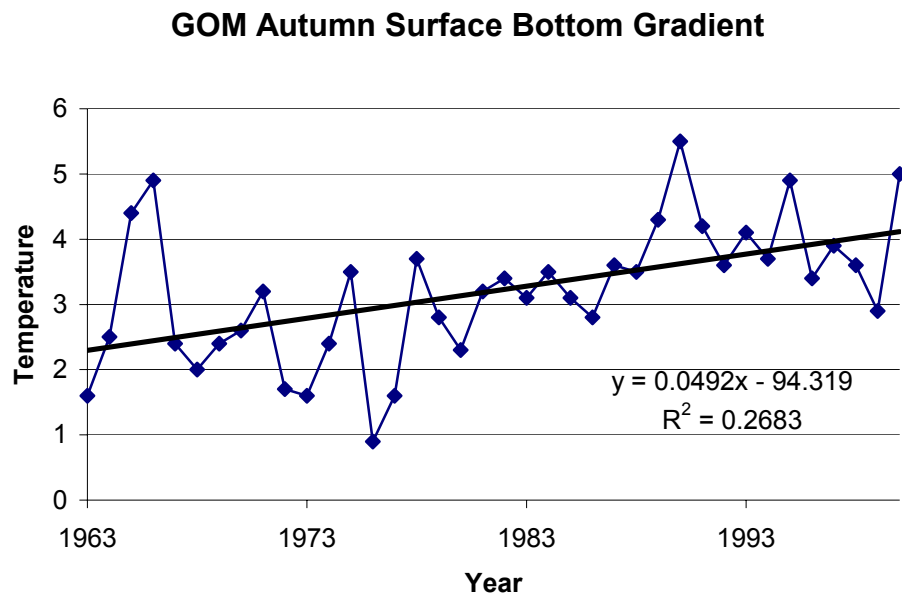
Figure 10.8  Surface-Bottom gradient from differencing the surface and bottom temperatures from the Gulf of Maine during 1963-2000

**GOM Surface Anomalies**
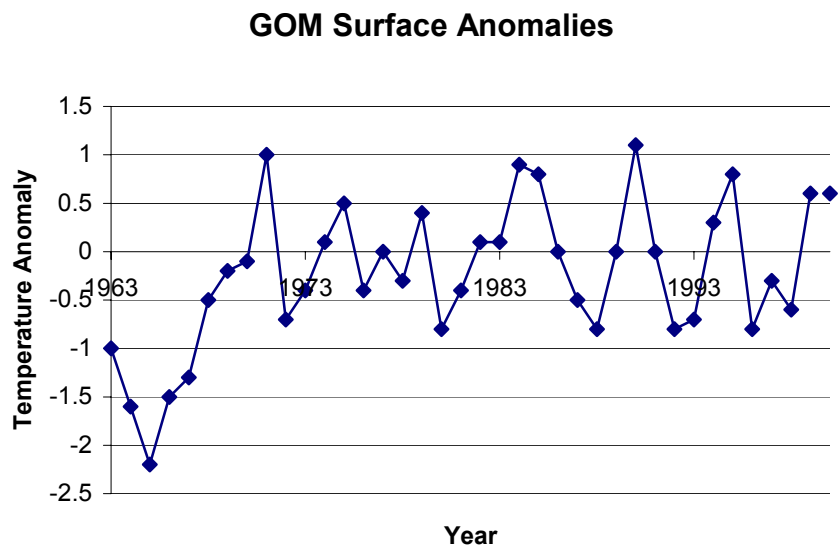
Figure 10.9.  Sea surface temperature anomalies for the Gulf of Maine during 1963-2000.

## Fall Survey Timing (Mean Julian Date)

$y = -0.9379x + 2148.8$
$R^2 = 0.6922$
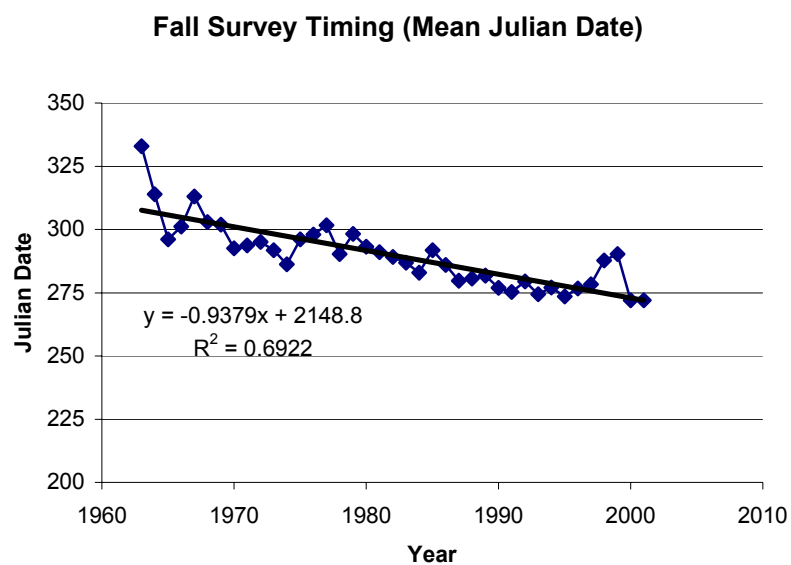
Figure 10.10.  Autumn survey timing (mean Julian date) during 1963-2001.

## Fall Survey Residuals VS Mean Survey Timing

$y = -0.0612x + 17.756$
$R^2 = 0.2729$
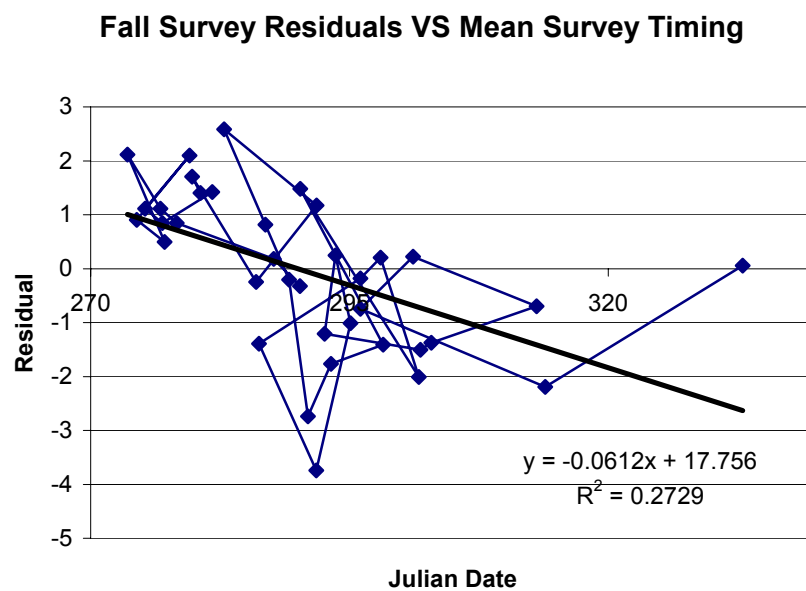
Figure 10.11.  Autumn survey residuals and mean survey timing (Julian date) for 1963-2000.

**GB Spring Surface-Bottom Gradient**
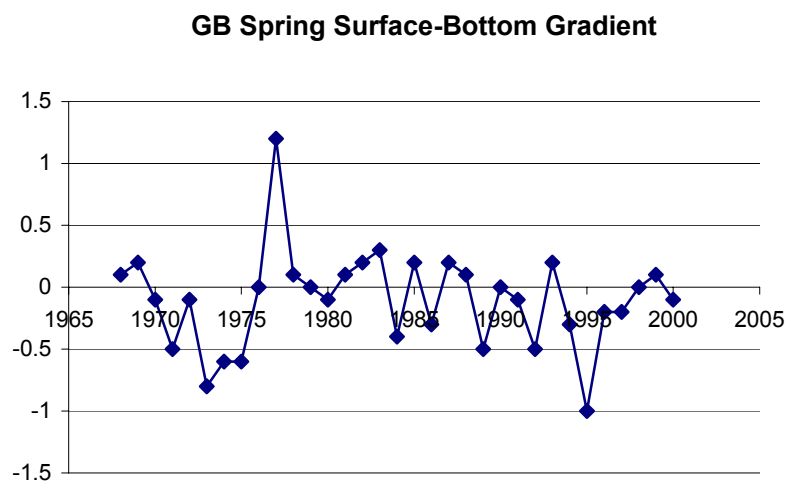


Figure 10.12. Spring surface-bottom gradient from differencing the surface and bottom temperatures from the Gulf of Maine during 1968

**Spring Survey Timing (Mean Julian Date)**



$y = -0.1345x + 361.91$

$R^2 = 0.0269$
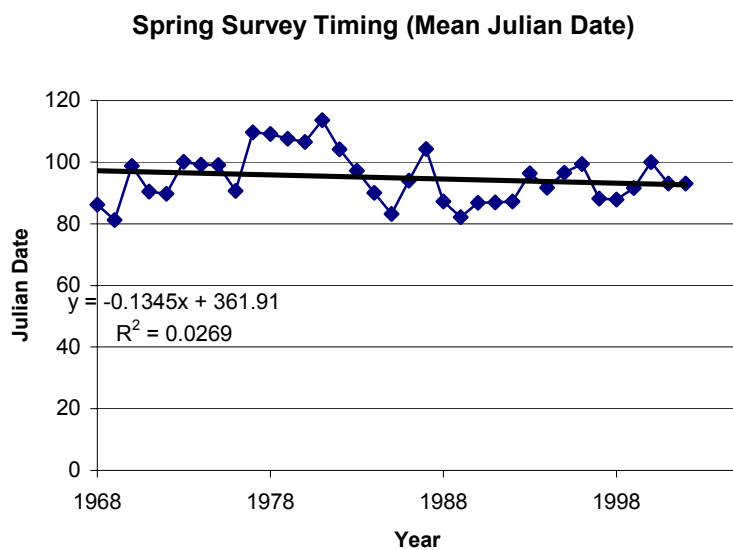
Figure 10.13. Spring survey timing (mean Julian date) during 1968-2002.
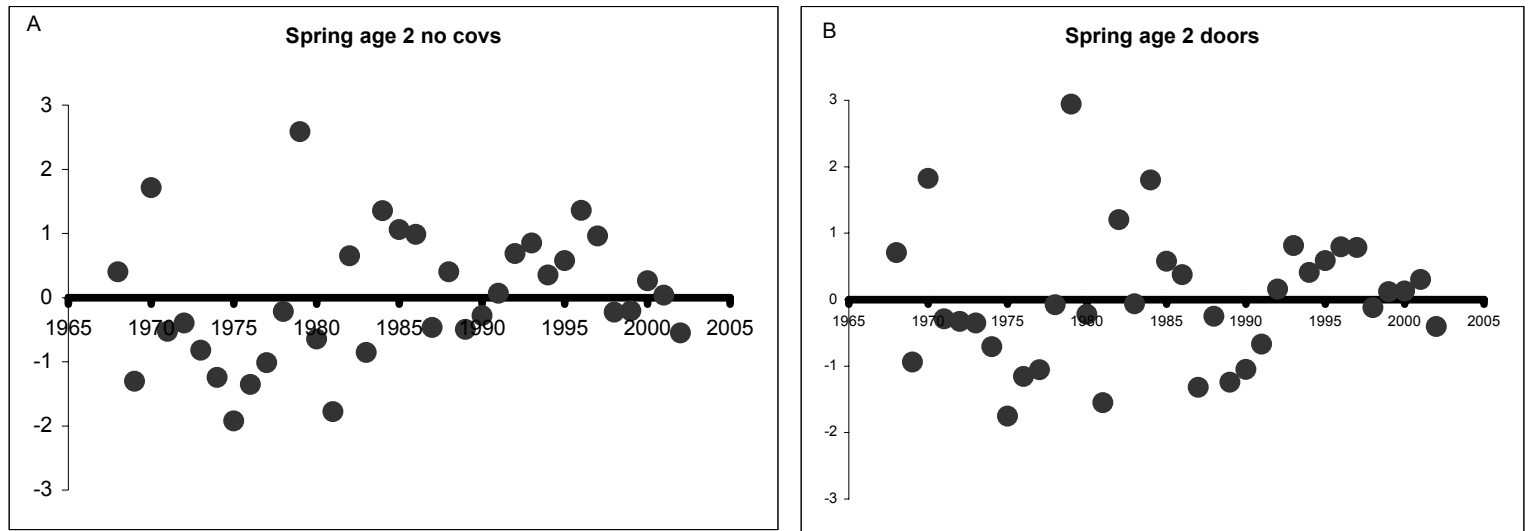
Figure 10.14.  Spring surveys age 2  weight/tow showing differences in residual patterns for age 2 without and with a door covariate (panels A and B) for 1968-2002
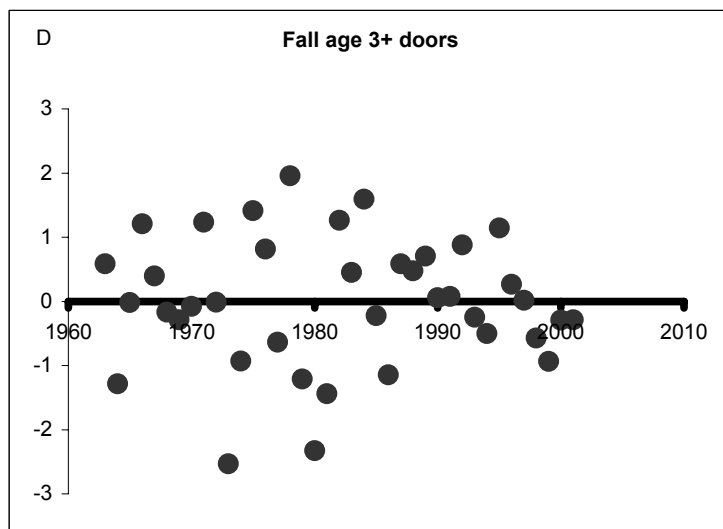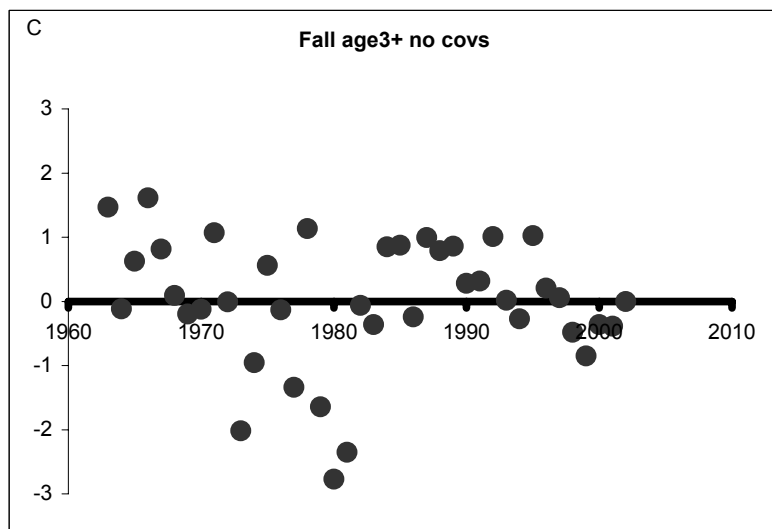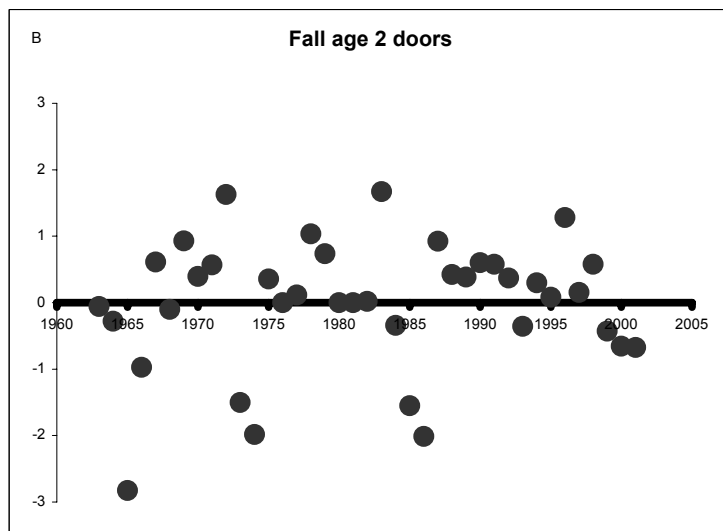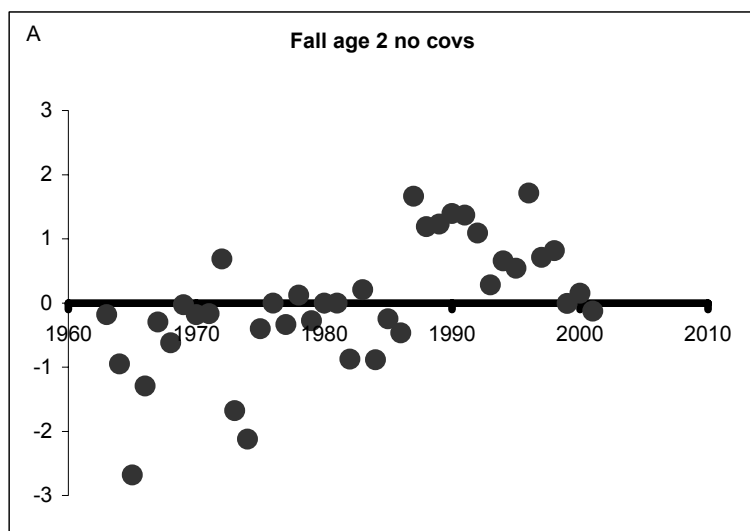
Figure 10.15. Autumn surveys age 2 and age 3+ weight/tow showing differences in residual patterns for age 2 without and with a door covariate (panels A and B) and age 3+ (panel C and D) for 1963-2002
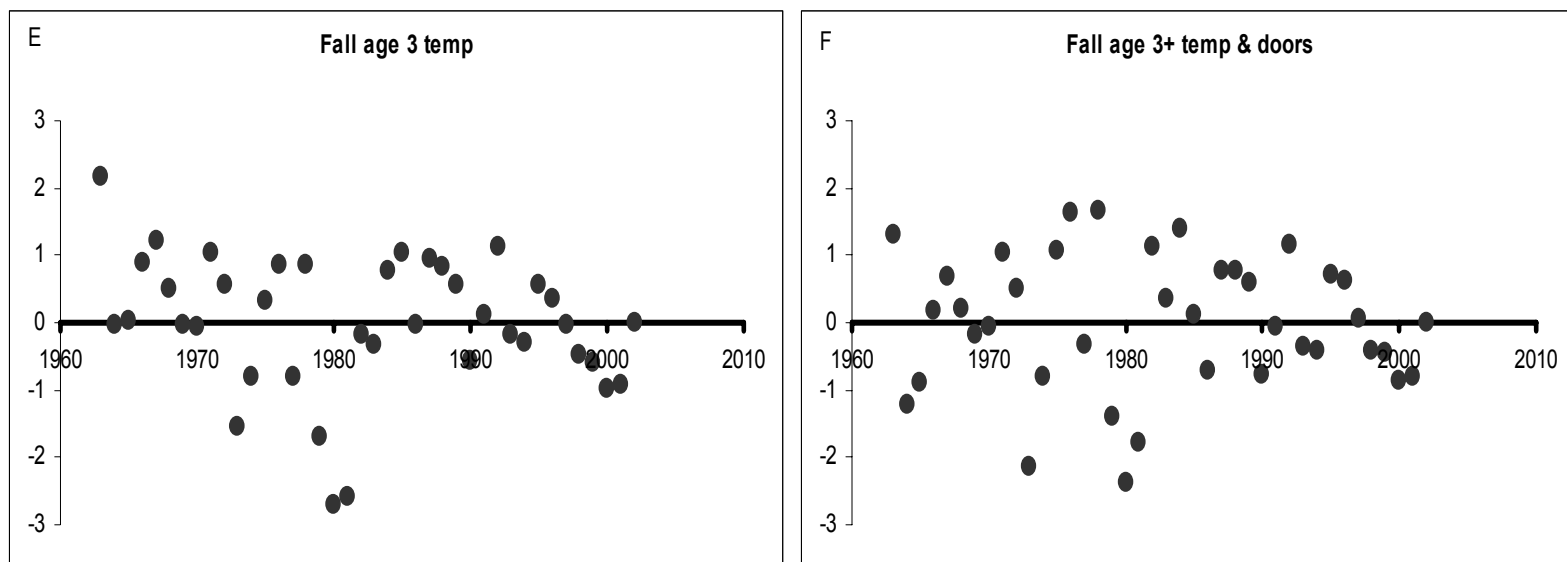
Figure 10.15 cont'd. Autumn surveys age 3+ weight/tow showing differences in residual patterns for age 3+ with a temperature and with a temperature and door covariate (panel E and F) for 1963-2002
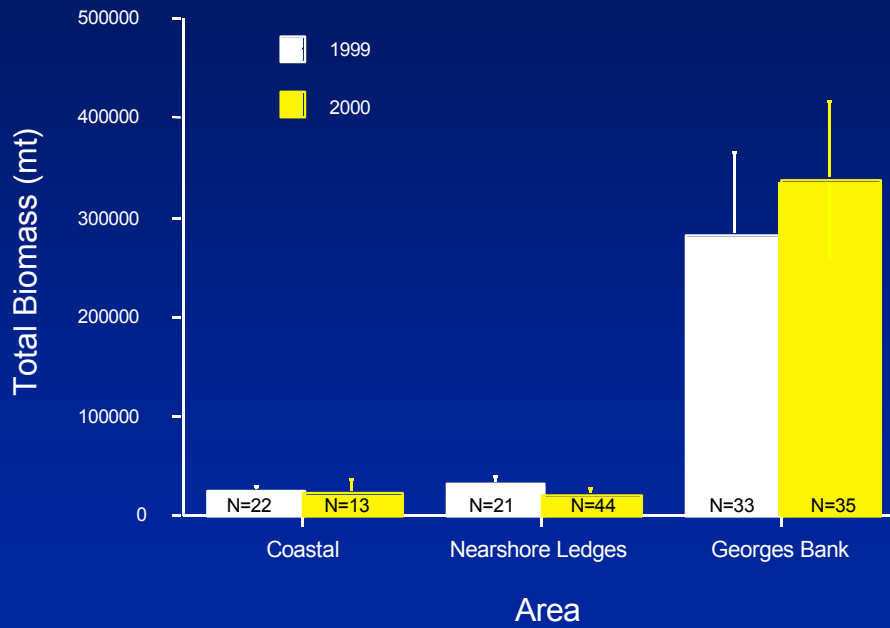
Figure 10.16. Average biomass estimates from F/V Providian for inshore and nearshore Gulf of Maine and Georges Bank during 1999 and 2000.
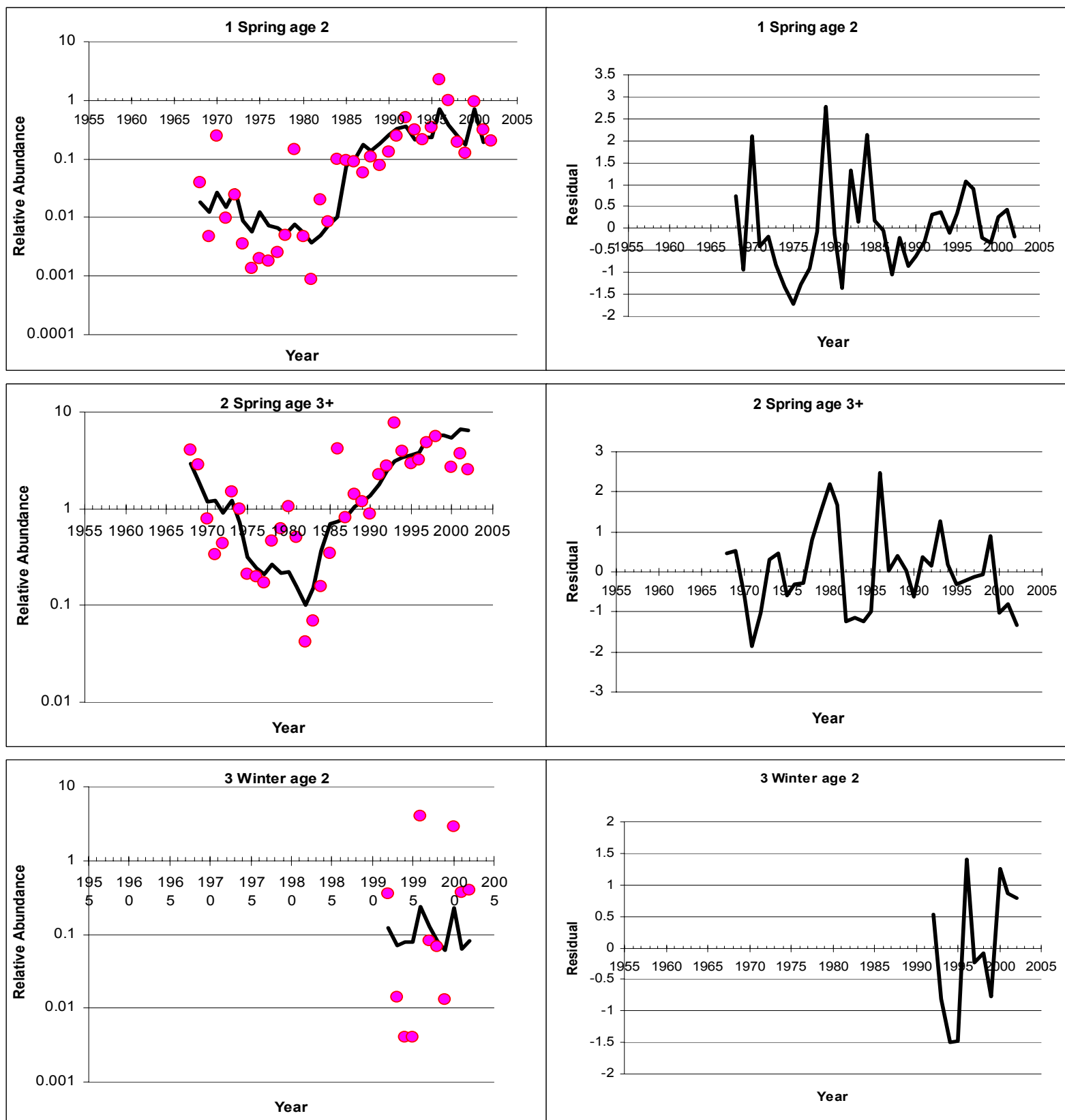
Figure 10.17. Observed vs predicted (log scale) and residuals vs time for the spring age 2, spring age 3+, and winter age 2 US surveys.
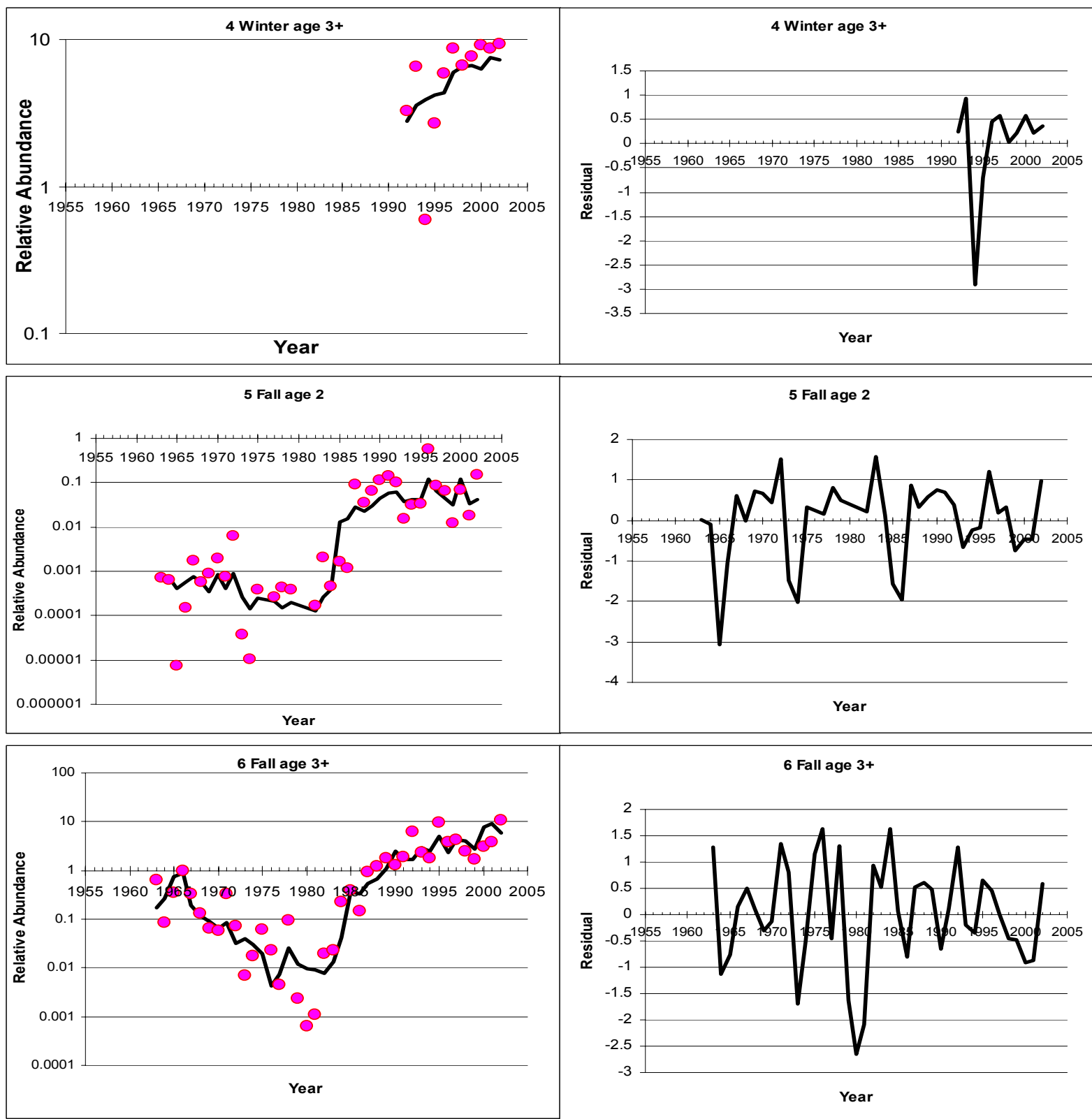
Figure 10.17 cont'd. Observed vs predicted (log scale) and residuals vs time for the winter age 3+, fall age 2, and fall age 3+ US surveys.
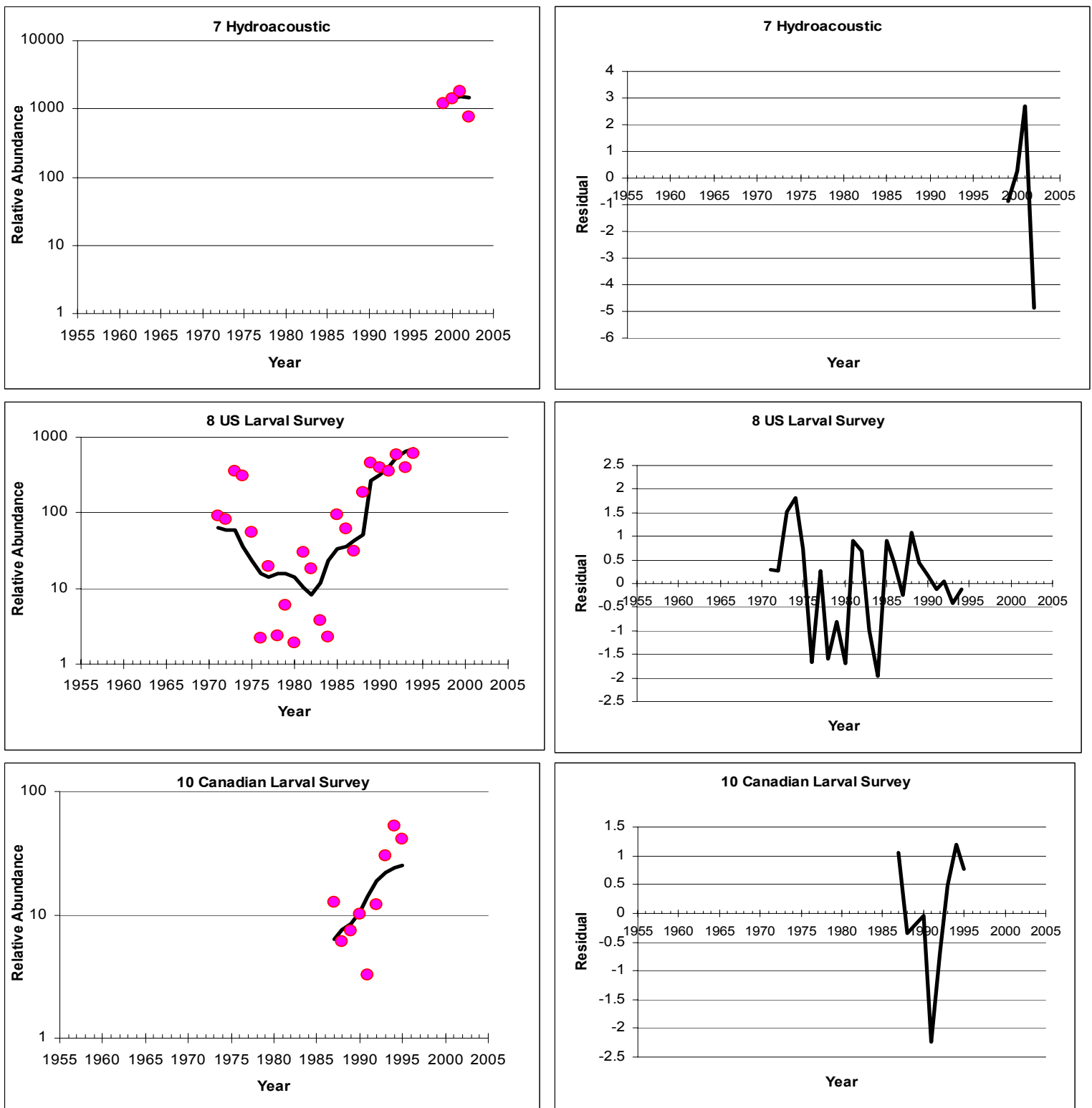
Figure 10.18.  Observed vs predicted, and residuals vs time for the hydroacoustic, US Larval survey, and the Canadian Larval survey.
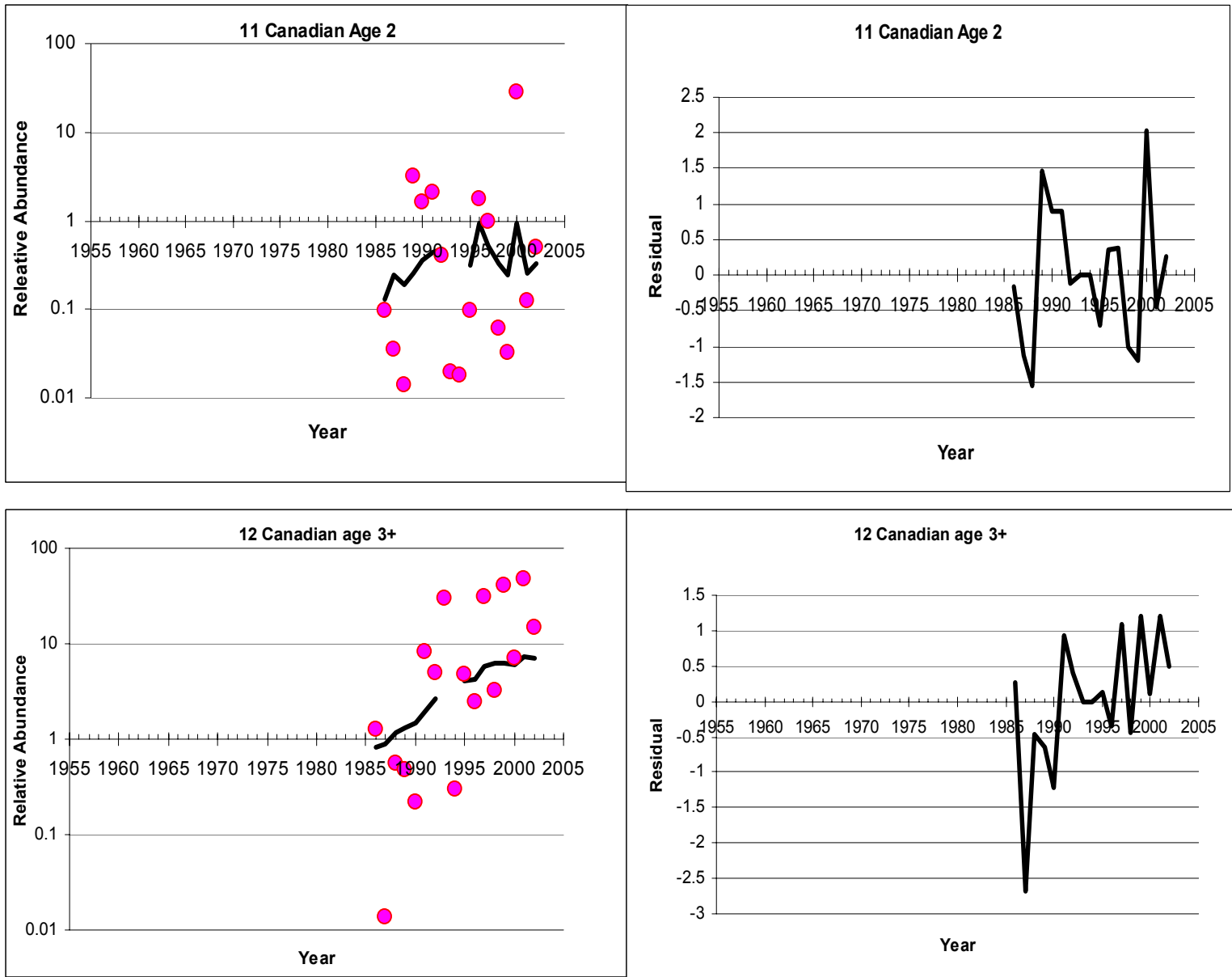
Figure 10.19. Observed and predicted relative abundance and residuals vs time.for the Canadian age 2 survey, and Canadian age 3+ survey